Site-specific Pilot Study:
Tsunami Hazard Assessment for Federal Insurance Rate Maps

Background. FEMA FIRM guidelines do not currently exist for conducting and incorporating tsunami hazard assessments that reflect the substantial advances in tsunami research achieved in the last two decades. Thus, current FIRMs rely heavily on the science, technology and methodologies developed in the 1970s, such as that of Houston and Garcia (1974) and Houston (1980). This work is generally regarded as groundbreaking and state-of-the-art for its time, but is now superseded by modern methods. Table 1 lists some of the advances in tsunami hazard assessment technology since 1990.

The U.S. National Tsunami Hazard Mitigation Program (NTHMP) incorporates these advances into site-specific tsunami hazard assessments for coastal communities in each of the five Pacific States of Alaska, California, Hawaii, Oregon and Washington (González et al., 2004). This program -- a NOAA-led

Table 1. Pre- and post-1990 methodologies for tsunami hazard assessment.

Component	Pre-1990	Post-1990
Runup Modeling	No	Yes
Far-field Sources	Earthquakes. Surface deformation based on simple elliptic analytic idealizations.	Earthquakes and landslides. Surface deformation based on geophysical models
Near-field Sources	No. Importance not recognized.	Yes. Importance now recognized as a result of numerous studies.
Bathymetry & topography	Low quality coverage and availability. Deep ocean modeled as constant-depth basin. Shallow coastal features not adequately resolved.	Improved quality, coverage and availability of Pacific deep and coastal bathymetry and topography.
Computational grids	Coarse-resolution.	Fine-resolution, where required.
Probabilistic Methodology	Based on short-term historical tsunami record	Based on long-term paleoseismic and paleotsunami records and short-term, historical earthquake and tsunami records.
Hazard Zone Identification	Qualitative estimates inferred from offshore height, only.	Indices can be computed, based on both runup heights and currents.

partnership with FEMA, USGS, NSF and the Pacific States -- is characterized by an infrastructure that includes a Hazard Assessment team in each State, with scientific and technical support provided by the NOAA Center for Tsunami Inundation Mapping Efforts (TIME) in Seattle, Washington. Each State

Hazard Assessment team includes tsunami modeling scientists, State Geotechnical scientists, and State Emergency Management professionals.

Since both FEMA and the NTHMP have national responsibility for tsunami hazard mapping – the NTHMP for hazard mitigation and emergency management and FEMA for the actuarial needs of the National Flood Insurance Program (NFIP) – ensuring consistency and the application of best available science to hazard map products is clearly in the national interest. To this end, NTHMP representatives were invited to two recent FEMA workshops to help develop plans for updating the existing FIRMs. Approximately 40 workshop participants included FEMA management, coastal engineering and scientific experts, floodplain management professionals and study contractors.

FEMA guidance at the first workshop encouraged a regional approach, in recognition that "one shoe seldom fits all" and that somewhat different methodologies are frequently required to properly account for regional differences. The second workshop concentrated on reviewing "Focused Study" plans developed by Technical Working Groups, including the Tsunami Focused Study.

The Tsunami Focused Study (Tsunami Study Group, 2004) identified two general types of tsunami sources as most common: earthquakes, which might be local or distant from the area of interest; and slides, which might be coseismic or aseismic, subaerial or subaqueous. Destructive tsunamis can be generated by both earthquake and slide sources, but the zone of destructive tsunami energy is generally characterized by a larger geographic scale for earthquake sources. In terms of the relative importance in of local and distant earthquake sources, there are five identifiable Pacific tsunami regions:

A. *Southern and Central California.* Local offshore fault systems; distant subduction zones.

B. *Cascadia (Northern California to Northern Washington and Straits of Juan de Fuca).* Local Cascadia Subduction Zone; distant subduction zones.

C. *Puget Sound.* Local Seattle, Tacoma, and other fault systems.

D. *Alaska*. Local Alaska-Aleutian Subduction Zone.

E. *Hawaii.* Distant subduction zones.

It is important to note that, within each region, slide sources can also pose a significant threat, with variations in the type and potential threat on a smaller geographical scale.

Upon review and discussion by workshop participants of the Tsunami Focused Study plan, the following recommendation was made:

> *"The recommended approach is to perform a comprehensive probabilistic tsunami hazard assessment at a pilot site in California or Oregon or Washington* [that includes]*: (1) recurrence interval estimate*[s] *of forcing functions and (2) propagation of tsunamis from Pacific Seismic Subduction Zones, (3) inundation calculations,* [and] *(4) probability distributions and integration."*

This document summarizes the recommended pilot study. For additional background information, a comprehensive discussion of tsunami hazard assessment issues, and additional technical details, see the Tsunami Focused Study plan (Tsunami Study Group, 2004).

Site Selection. Eight candidate sites were considered: Willapa Bay, Washington; Seaside, and the Coquille, Sixes and Rogue River communities in Oregon; Palos Verdes, Santa Barbara and Crescent City in California. An inventory and review was conducted of selection factors that included: paleoseismic and paleotsunami evidence, the state of knowledge regarding source recurrence, the existence of historical tsunami records, the availability and quality of data needed for the development of computational grids, and programmatic factors that governed whether this first Pilot Study should be conducted in FEMA Region IX or X. Seaside, Oregon, and Crescent City, California, were judged to be the most promising candidate sites, and programmatic considerations ultimately led to the selection of Seaside.

Study Plan. The historic and prehistoric record demonstrates that Seaside is at risk from both near- and far-field tsunamis. Near-field tsunamis can be generated locally by Cascadia Subduction Zone earthquakes; far-field tsunamis can be generated by earthquakes in more distant fault zones around the Pacific, especially the Alaska-Aleutian Subduction Zone. Accordingly, this site-specific study must assess the probability of occurrence and the potential impact on Seaside of all such potential sources, through completion of the following tasks:

1. **Identify source parameters and uncertainties.** Specify seismic and submarine landslide source parameters. This step produces the initial conditions, i.e., fluid displacement and velocity fields, for the propagation and runup model and is deemed to be the most formidable step in the process, since scientifically-defensible techniques are needed for quantification.

2. **Estimate recurrence intervals**. Associate each far-field and near-field source with a recurrence interval estimate. This is also a difficult task in the process, since uncertainties in the underlying fault rupture and landslide processes are large.

3. **Model tsunami runup and overland flow velocities.** Use state-of-the-art numerical models to simulate tsunami propagation from the source to runup on land. In contrast to troublesome empirical attenuation relations used to estimate seismic ground-shaking hazards, tsunami wave height can be accurately predicted through numerical simulations.

4. **Perform probabilistic calculations to develop 100-year, 500-year, and "worst-case" events.** Use computed runup values and their frequency of occurrence to express the modeling results in terms of 100-year, 500-year and "worst case" estimated wave heights for the purposes of the NFIP.

5. **Compare probabilistic calculations to paleotsunami data.** Use age dates of available tsunami deposits to compare with the estimates obtained in Task 4.

6. **Assess CCM hazard zone guidelines.** Use Task 3 numerical output of tsunami wave height and currents with available methodologies to develop estimates of hazard zone parameters, such as design flow elevation (DFE) and maximum velocity. Compare these estimates with one another and with the CCM recommended methodology.

7. **Evaluate the relative importance of tsunamis and other hazards.** Compare the events developed in Task 4 with other hazardous phenomena, such as storm surge and wind waves, from hazard assessment studies already conducted, if the study results are readily available.

8. **Produce hazard map.** Develop a hard-copy map representation of the events defined in Task 4.

9. **Create distributed database.** Develop a web site with links that provide access to all data related to the pilot study: bathy-topo data and grids; source parameters; model output; geophysical data; derived products; reports; etc.

10. **Publish final report.** Prepare and publish a joint NOAA/USGS/FEMA Technical Report that documents the study and compares the results with the previous Seaside Flood Insurance Study of (FIA, 1979) and FIRM (FEMA, 1981).

Deliverables and Milestone Schedule. On receipt of funding, an intensive 6-month effort will be initiated, culminating in delivery of the following products.

Deliverables

- Seaside, OR Tsunami Hazard Map
- Distributed database for Seaside Pilot Study
- Final Report draft (publication of NOAA/USGS/FEMA Tech Memo within 2 months), including:
    - Methodology for Tsunami Hazard Assessment
    - Comparison of tsunami and other hazards
    - Assessment of CCM Tsunami Hazard Zone guidelines
    - Database Users Guide
    - Recommendations

Milestone Schedule

The work will be completed on a 6-month schedule. This schedule is ambitious, as the average duration of an NTHMP modeling and mapping effort for a single “worst-case” scenario has typically been 12 months. This Pilot Study requires a higher level of effort, with multiple source scenario simulations, statistical analyses of the results, comparison with other available studies and a research effort aimed at improved identification of tsunami hazard zones. Consequently, the work strategy must exploit every possible efficiency, including:

- The NTHMP Hazard Assessment infrastructure to create a highly focused NOAA/USGS/FEMA/State collaboration
- The TIME Center’s
    - Grid-development expertise
    - Database of Pacific-wide generation/propagation simulations
    - Newly created computer cluster for multiple runup simulations
- TIME, USC and other academic modeling expertise
- USGS and Oregon academic geophysical expertise
- USC Coastal Engineering expertise
- FEMA commitment and involvement at every stage of the study

On receipt of funds, the NOAA TIME Center will coordinate the efficient utilization of these resources to ensure the following schedule is met:

Month	Milestone
1.5	Complete computational grid system.
2.0	Complete implementation and testing of runup model
	Complete specification of sources
	Begin runup production runs
3.5	Complete runup modeling
	Complete source recurrence interval estimates
	Complete runup frequency curves
	Begin assessment of CCM hazard zone guidelines
4.5	Complete characterization of 100-yr, 500-yr and worst case events
	Complete comparison of tsunami with other hazards
5.5	Complete hard copy hazard map
	Complete distributed database
	Complete assessment of CCM hazard zone guidelines
6.0	Complete draft of NOAA/USGS/FEMA Technical Report

Budget. This focused will require $270.5K in supplementary funding. Of this, $26K is for the salaries and travel expenses of two PMEL senior scientists and $244.5K for contracts to perform specific studies required to complete the tasks outlined in the Study Plan, above. Contributions in salaries and computing costs by NOAA ($70.0K) and USGS ($71.5) total $141.5K, or approximately 34% of the total cost.

PMEL Salaries	$25,000
PMEL Contracts	
Probability Study	$79,500
Modeling Study	$66,000
Impacts Study	$80,000
GIS Analysis & Maps	$20,000

Total	$270,500

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